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Effect of Strain Rate on the Formation of the Microstructure of a 1950/10% SiC Metal Matrix Composite under High Temperature

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Abstract. The paper studies the effect of strain rate on the formation of grains and low-angle boundaries in an aluminum matrix composite based on the 1950 alloy (analogous to the AA7075 alloy) with 10 vol% SiC. The deformation of the metal matrix composite, produced by a powder technique, is investigated at a temperature of 500 °C. The specimens are investigated by electron backscatter diffraction before and after deformation at strain rates ranging from 0.1 to 5.5 s⁻¹. It has been established that continuous dynamic recrystallization occurs in the composite at 500 °C in the whole strain rate range considered. The recrystallization is followed by a decrease in the average grain diameter and an increase in the density of the low-angle boundaries with increasing strain rate.

INTRODUCTION

Metallic composites based on an aluminum matrix are widely used in aerospace equipment as a substitute for aluminum alloys in products for which strength characteristics and service life must be higher than those for products made of aluminum alloys. When designing new technologies for manufacturing preforms and products (especially made of composites), and studying the effect of thermomechanical processing on the physical and mechanical properties of materials, one should use computer simulation. To make correct computer simulation, it is necessary to specify a flow stress model, which would adequately describe the rheological properties of the composite for the considered temperature–strain-rate conditions of deformation. The model considers explicitly the internal material structure and the physical processes of hardening and softening. Therefore, to develop and verify a new flow stress model, it is necessary to use experiential data about the influence of thermomechanical processing on flow stress and microstructure formation. The microstructure is characterized by average grain diameter, low-angle boundary density and other quantities.

The work deals with studying the strain rate effect on the formation of grains and low-angle boundaries in a 1950/10% SiC metal matrix composite at a temperature of 500 °C.

MATERIAL AND INVESTIGATION PROCEDURE

We studied the microstructure of a composite with a matrix made from the 1950 aluminum alloy (analogous to the AA7075 alloy) with 10 vol% of SiC particles. The composite was manufactured at the All-Russian Scientific Research Institute of Aviation Materials by sintering a powder mixture of the 1950 alloy and SiC reinforcement particles without subsequent compaction. The average diameter of the 1950 alloy powder particles was 40 μm and the size of the SiC particles was 4 μm [1].

Cylindrical specimens with a diameter of 6 ± 0.1 mm and a height of 9 ± 0.1 mm were made from the investigated metal matrix composite (MMC). We compressed these specimens by a plastometric unit at a temperature of 500 °C according to the technique described in detail in [2]. The specimens were heated up to the test temperature for 1 hour. The microstructure of the specimens was studied in the as-received condition before and after deformation. To study the microstructure of the specimens before deformation, we heated a MMC specimen up to 500 °C for 1 hour and then cooled it in water.

The microstructure was studied by electron backscatter diffraction (EBSD) with the use of a Tescan Vega II XMU raster electron microscope with HKL Nordlys F+ (Oxford). For EBSD analysis, the specimens underwent mechanical and then electric polishing. The latter was made in the 11% H_2O +40% H_2SO_4 +45% H_3PO_4 +3% CrO_3 (in wt%) electrolyte heated to 70 °C. The average duration of polishing was 6 s, with a voltage of 15 V and a current density of 0.1 A/mm². The scan step in the EBSD analysis was 0.3 μ m. The size of the scanned region was 300×300 μ m. The grains were considered to have a misorientation exceeding 15°, with the misorientation of the subgrains ranging between 2 and 15° [3]. The grain diameter D was calculated by the formula

$$D = 2\sqrt{\frac{S_g}{\pi}},$$

where S_g is the grain area, μ m².

The density of the low-angle boundaries P in the specimens was calculated by the formula

$$P = \frac{L}{S},$$

where L is the total length of the boundaries measured in microns, with the misorientation ranging between 2 and 15°; S is the area of the indexed matrix of the composite (μ m²).

RESEARCH RESULTS AND DISCUSSION

Figures 1a and 1b show three time dependences of the specimen strain rate (loading form I, II and III). Figure 1c presents strain dependences of flow stress for the 1950/10% SiC MMC at a temperature of 500 °C. These curves correspond to loading forms I, II and III.

Figure 2 shows EBSD images of the microstructure of the 1950/10% SiC MMC in the as-received condition (see Fig. 2a) before deformation at 500 °C (see Fig. 2b), after deformation at 500 °C for loading forms I (see Fig. 2c) and III (see Fig. 2d).

The table presents data on the average grain diameter D and the density of the low-angle boundaries P for the 1950/10% SiC MMC in the as-received condition before and after deformation.

TABLE 1. Average grain diameter D and the density of low-angle boundaries P in specimens made from the 1950/10% SiC composite

Specimen state	Average grain diameter D , μ m	Density of low-angle boundaries P , 1/ μ m
As-received condition	3.09	0.00320
Before deformation and after heating to 500 °C	4.62	0.00096
After deformation according to loading form I at 500 °C	3.63	0.00110
After deformation according to loading form III at 500 °C	3.46	0.00168

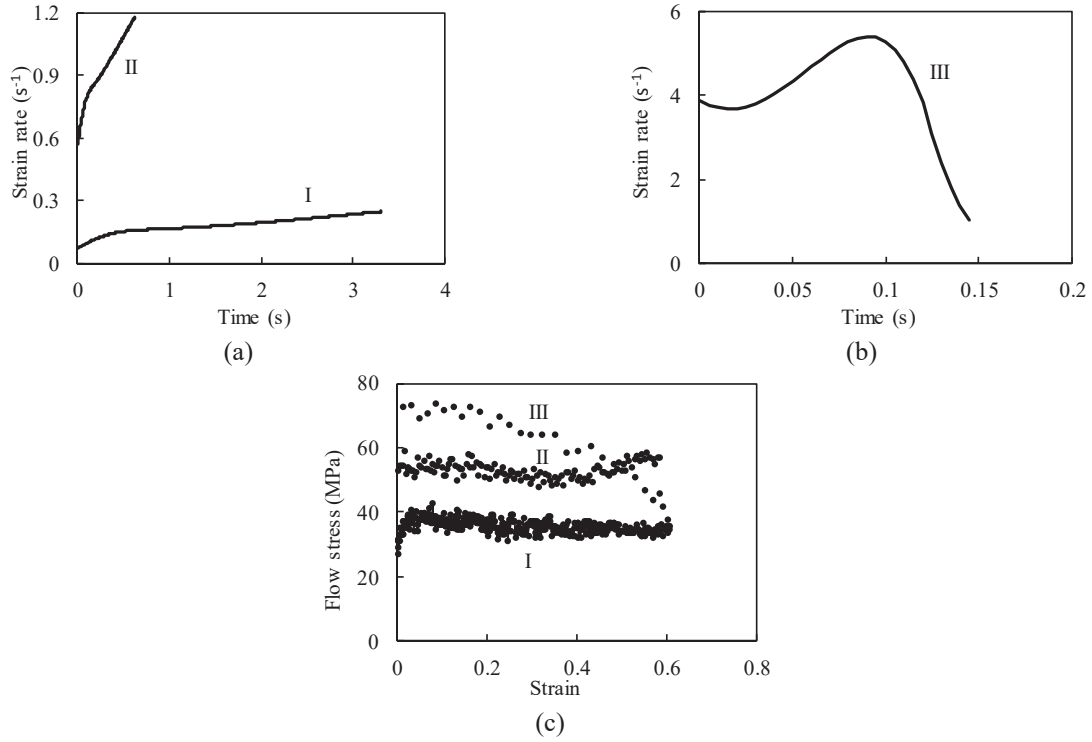


FIGURE 1. Time dependences of strain rate (a, b) and strain dependences of flow stress (c) at 500 °C for the loading forms shown in (a) and (b)

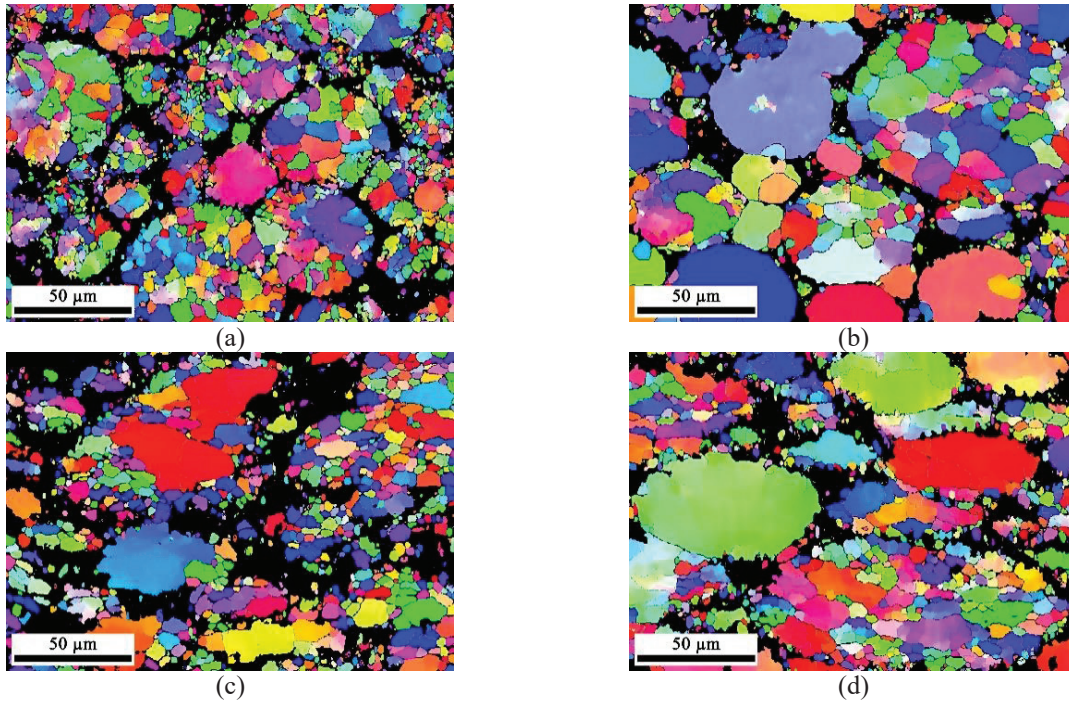


FIGURE 2. EBSD microstructure images of the 1950/10% SiC MMC in the as-received condition (a) before deformation at 500 °C (b), after deformation at 500 °C for loading forms I (c) and III (d)

The EBSD shows that continuous dynamic recrystallization (CDR) occurs under plastic deformation in the composite at 500 °C for the whole strain rate range between 0.1 and 5.5 s⁻¹. The CDR is followed by a decrease in the average grain diameter and an increase in the density of the low-angle boundaries (see the Table). It is obvious from the table that the increase in the strain rate results in a decrease in the average grain diameter and an increase in the density of the low-angle boundaries. It can be explained that increasing strain rate results in increasing dislocation density. This, in turn, increases the amount of subgrains at the initial stage of recrystallization. The subgrains grow under increasing strain, and they increase their own misorientation in relation to neighboring subgrains. The subgrains become grains at a misorientation of above 15°.

CONCLUSION

The obtained microstructures of specimens made from the 1950/10% SiC MMC after deformation at a temperature of 500 °C, at strain rates ranging between 0.1 and 5.5 s⁻¹, correspond to a typical microstructure obtained under conditions of continuous dynamic recrystallization.

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